UNITED STATES DEPARTMENT OF ENERGY
NAVAL PETROLEUM RESERVES IN CALIFORNIA

TECHNICAL REPORT

GEOLOGY OF THE TUPMAN AREA

NAVAL PETROLEUM RESERVES #1 KERN COUNTY, CALIFORNIA

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December, 1993

III. Introduction

Purpose and scope. Several public comments were received on the Draft Supplemental Environmental Impact Statement (DSEIS) requesting more technical work be added to support geologic and geohydrology discussions and conclusions. Moreover, a recent Elk Hills groundwater study (Golder Associates, 1990) focused on the need for further groundwater characterization in the NE flank area. This effort is part of ongoing groundwater characterization studies in response to NPRC Tiger Team (91) Corrective Action EAP-013, "Characterization of the Hydrologic Regime," for Finding No: GW/CF-3.

Location. The study area includes portions of sections 23S, 24S, 25S, and 26S, T. 30S., R. 24E., on the NE flank of NPR-1 (figure 1). Locations of interest within the study area include the 23S tank farm and percolation pits, 25S LACT facility (site), and the Town of Tupman. Much of the study area is accessible only by foot because of restricted off-road driving. Many older roads have been revegetated and subsequently closed. The long-abandoned "U" group of wells, in the S½ of section 26S, will be discussed in terms of past oilfield practices. There are only three currently producing wells in the entire study area: 382-25S, 31BM-26S, and 87BM-26S.

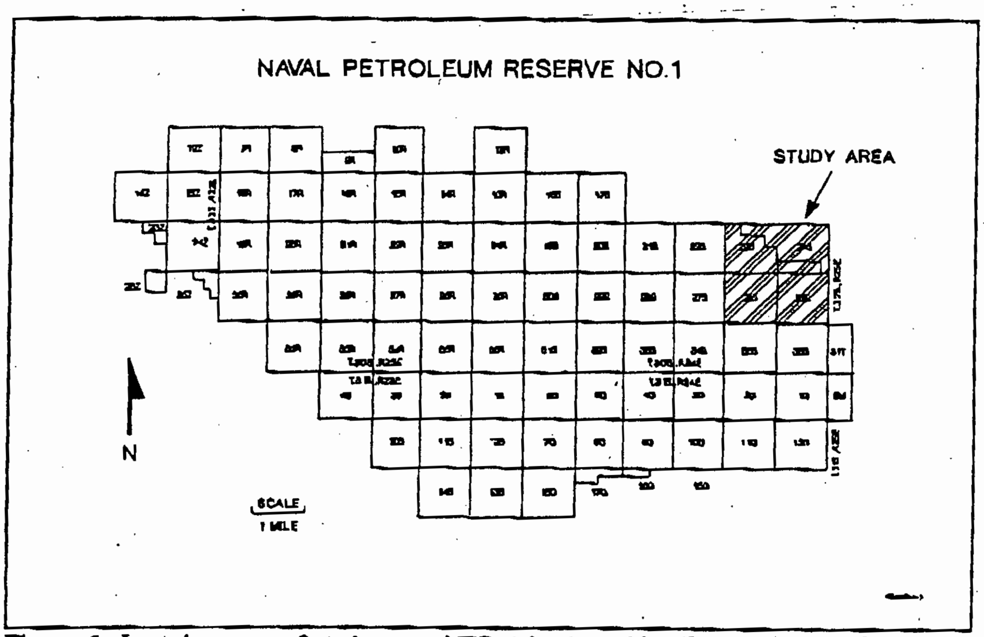

Figure 1. Location map of study area. NPR-1 is about 23 miles southwest of Bakersfield.

The importance of smaller Tulare faults seen on the surface is unknown due to a lack of subsurface data. The name "Tupman Fault" is given to a spectacular fracture cutting post-Tulare fan deposits with observed strike-slip and vertical displacements. The Tupman Fault (previously referred to by Woodring and others (1932) as an "earthquake crack") does not cut surficial deposits younger than the Tulare fan.

Brea deposits of solidified oil and sand underlie modern drainages. The fluids have long stopped flowing and the deposits do not appear to endanger plants or wildlife. According to previous studies on NPR-2, hard brea in natural channels should remain intact. Other areas of concern include the 23S sump and 25S LACT sites.The cyclic fining-upward sequences of the Tulare would greatly restrict any downward movement by groundwater. Faults appear to act as barriers to lateral groundwater movement and may be in part responsible for a groundwater mound along the crest of the Elk Hills anticlinal structure.

II. Conclusions and Recommendations

Conclusions. Geologic mapping of the NE flank area of NPR-1 shows that the relationships between the Tulare and several mappable surficial units to be far more complex than simple Tulare/alluvium contacts depicted by previous workers. Faulting and folding in the Tulare may be related to wrenching, thrusting, or gravity mass movement. Tulare groundwater is connate and not moving off NPR-1 due to structural control and a lack of recharge. Although surface discharges of produced fluids have occurred in the past, none are currently in effect within the study area.

Recommendations. Existing data on Tulare/alluvium contacts on NPR-1 need to be reconsidered in light of much more complex stratigraphic relationships uncovered through detailed surface mapping. Faults exposed at the surface, particularly the Tupman Fault, may be groundwater barriers as suggested by well log interpretations of Tulare faults in an area adjacent to the study area. Brea deposits should not be remediated.

GEOLOGY OF THE TUPMAN AREA, NAVAL PETROLEUM RESERVES #1 KERN COUNTY, CALIFORNIA

Mark Milliken

December, 1993

I. Management Summary

The purpose of this project is to investigate and geologically map the various rock units of the Tulare Formation (hereafter referred to as "Tulare") and surficial sediments of the Tupman area, NE flank NPR-1. The area includes sections 25S, 26S and portions of 23S and 24S, T. 30 S., R. 24 E. Included in the study area are the 23S sumps, the 25S LACT site, and the town of Tupman. This effort is part of ongoing groundwater characterization studies in response to NPRC Tiger Team (91) Corrective Action EAP-013, "Characterization of the Hydrologic Regime," for Finding No: GW/CF-3.

The Plio-Pleistocene Tulare consists of gravel, sand, silt, clay, and limestones. The Tulare depositional environment was a broad apron of coalescing alluvial fans and deltas emanating from mountain ranges to the west and south. Rivers shifted back and forth along the plain, abandoning old channels and scouring new ones. Fining upward sequences culminate in quiet water clay and limestone, suggesting channel abandonment. Subsequent coarsening upward cycles suggest diversion of stream channels into the lake basins. The mapping of limestone outcrops assists in determining bedding attitudes.

Surficial alluvial deposits postdate the Tulare and include older fan deposits, older alluvium, flood plain deposits of the ancestral Kern River, and modern alluvium. Older fan and alluvium deposits were laid down during periods of high runoff, possibly coincident with Sierran glacial events within the past 1 Ma (million years). No datable materials have been found to provide absolute age dates of any mapped rock units.

Structural features include faulting and minor folding, primarily limited to the Tulare. The Tulare in general dips to the northeast at 4°-7°, with dips as much as 19° near faults. Major faults oblique to the Elk Hills anticlinal axis and mapped by previous workers are confirmed to exist in the study area, but are buried by surficial deposits younger than the Tulare.

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TECHNICAL REPORT

ANALYSIS OF SURFACE FRACTURES ASSOCIATED WITH DISPOSED WATER BREAKOUT OF WELL 58WD-7G, 10/23/93

By
Mark Milliken
DOE Staff Geologist

November, 1993

ANALYSIS OF SURFACE FRACTURES ASSOCIATED WITH DISPOSED WATER BREAKOUT OF WELL 58WD-7G, 10/23/93

Summary and conclusions. On October 23, 1993, produced water being injected into the Tulare Formation broke through to the surface at a location about 1060 ft northeast of well 58WD-7G. A field investigation on Monday, October 25 uncovered a pattern of fractures on the surface along a linear zone trending N. 18° E. from the well. Careful examination of the fractures shows they tend to increase in age southward from the breakout. The trend of the fracture zone is similar to linear trends within exposed Tulare rocks. The surface fractures were probably caused by reservoir pressures that exceeded the fracture gradient for the Tulare. The fractures apparently propagated from south to north over a period of several weeks, culminating in flow to the surface at a topographically low area.

Background. Produced water was discovered flowing from erosional depressions on the surface northeast of well 58WD-7G at about 6 PM on Saturday, October 23, 1993. There was some initial confusion about which well was responsible, and about 24 additional hours went by before 58WD-7G was shut off and flow stopped. BPOI estimates a total loss of about 10,000 bbls of produced water. The spill was limited to small drainages flowing into the larger creek bed near the road. Water flowed along only about 400 ft of the drainages, suggesting the spill was less than 10,000 bbls, or that the water quickly percolated into the ground.

On October 25, a field party consisting of Tony Reid, Harvey Deutsch, and myself visited the location. Several fresh fractures were noted around the breakout vicinity. The fractures continue to the southwest, aligned along a northeast-southwest trending zone. The fractures stop on a ridge about 500 ft southeast of the breakouts. On the ridge near hill 786.97, the alignment of the fracture zone with well 58WD-7G became obvious. On October 26, I made a follow-up visit to photograph the fractures and take detailed notes. The fractures showed evidence of different ages, and they were oriented oblique to the general trend of the fracture zone. Rough locations of the fracture zone and breakouts were triangulated using a Brunton compass. The approximate location of the largest breakout is 1060 ft from well 58WD-7G on a bearing of N. 18° E. (figure 1). The breakout coordinates are roughly 1370' N., 1883' W. of the SE corner, section 7G.

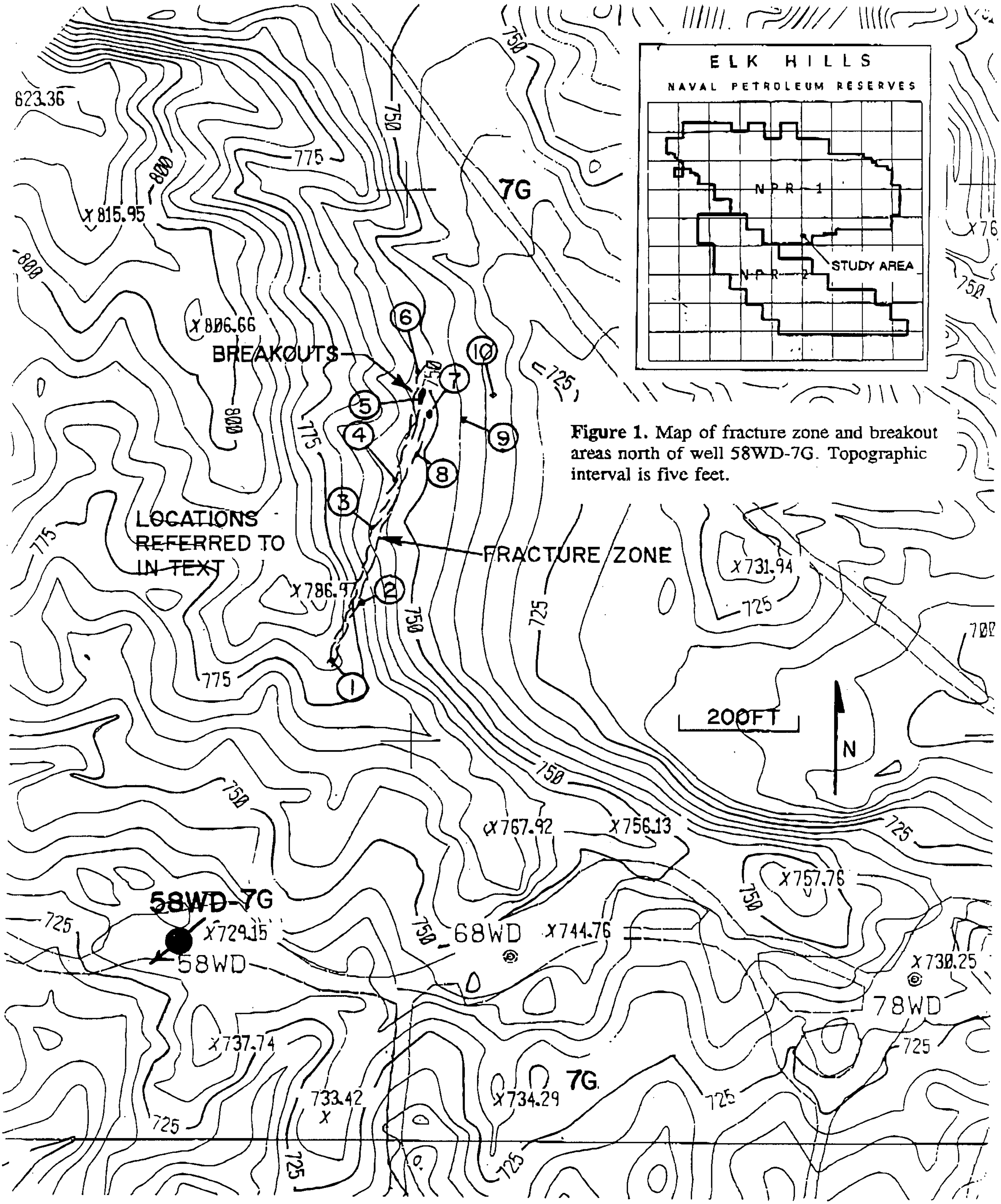


Figure 1. Map of fracture zone and breakout areas north of well 58WD-7G. Topographic interval is five feet.

Fracture timing. The fractures appear to be oldest at the southern end of the fracture zone. The youngest fractures are in the immediate vicinity of the breakouts. This relationship suggests that fractures propagated south to north, culminating in water to the surface at a topographically low spot. The older fractures are on the order of weeks older than the youngest, suggesting that the fractures propagated over a period of weeks before surface flow began. Very fresh fractures near the breakouts probably formed within days or concurrent with surface flow.

The criteria for determining relative ages of fractures are:

1. **Width of fractures.** Older fractures are generally wider, some exceeding 0.5". Younger fractures commonly do not exceed 0.1" in width.

2. **Sharpness of fracture edges.** The edges of older fractures are weathered and rounded, while younger fractures are sharp and well-defined.

3. **Fill material.** The older fractures are commonly filled or overlain by plant, soil, and rock debris moved primarily by animal activity. Younger fractures are generally clean and often cut through recent animal excavations.

Fracture orientation. The fractures occur in a left-stepping *en-echelon* pattern along a 10 ft wide zone. The zone is about 500 ft long and begins 560 ft northeast of well 58WD-7G (figure 1). The fracture zone strikes N. 18° E., and the fractures are oriented ±20° obliquely to the east. Fracture trends range from N. 20° E. to N. 55° E., with the strongest trend being between N. 30°-50° E. (figure 2). Some fractures are oriented to the NW and may not be associated with the subject fracture zone.

Cause of fracturing. The fracturing is clearly related to the release of disposed water at the surface. The surface disturbance may be an extension of a pre-existing fracture at depth reactivated by increased injection pressure in Tulare rocks. No lineament analysis was done within the area surrounding the fracture zone. Airphotos do show weakly developed NE trends in drainages and photo-linears, although there is no specific indication of surface jointing coincident with subject fracture zone. The strongly developed left-stepping *en-echelon* fracture fabric suggests right-lateral wrenching may be involved.

pressures.

Exhibit 2 is a copy of the rate-pressure test for well 58WD-7G conducted in 1991. Tubing fracture pressure was 251 psi. Well 58WD-7G is the latest well to surface, having done so on October 23, 1993. Nominal tubing pressure/rates were 125 psi/25,000 B/D prior to 10/23. It was during this time that fracturing to the surface gradually occurred, culminating in flow to the surface. Fracturing occurred at pressures far less than the 251 psi frac pressure obtained in the test. Milliken feels that fractures induced during the 1991 test probably laid the foundation for shallower fracturing in zones of lower overburden pressure. The pressure and rate for 58WD-7G was increased on 10/23/93 after the spill was recognized and inadvertently attributed to well 38WD-7G. Milliken feels that a secondary breakout occurred during this spike. Since 10/23/93, pressures and rates have been greatly reduced to avoid further water to the surface, but standing water and seeping gas at the secondary breakout still occur. Well 58WD-7G may never be able to inject at rates much above 15,000 B/D without flowing to the surface, unless the fractures are allowed to close and heal themselves with time.

Exhibit 3 is a copy of the chart for well 58WD-7G during the week of October 23, 1993. Fracturing of the surface occurred over a long period prior to Oct. 23, during which time the injection rates were a nominal 25,000 B/D. Flow to the surface occurred prior to the kick to 27,874 at 6:30 PM on Oct. 23. Surface flow was enhanced by the kick, and continued from two adjacent point sources until 6 PM on Sunday, Oct. 24.

Exhibit 4 shows flow rates and tubing pressure data for well 58WD-7G for the periods before and after Oct. 23. Associated charts show injectivity (B/D per psi) and flow rates for the period. Injectivity increased markedly after the Oct. 23 breakout, suggesting the fractures may have allowed injected water access to stratigraphically higher gravels. Standing water in the breakout depression occurs at an injection rate of 15,000 B/D. When the rate is reduced, the standing water disappears.

4. Case histories and remediation success in other fields. Waldron discussed Chevron's success in their water disposal program at Kern River. He mentioned the similarities in well spacing between that project and the our 7G/18G disposal area. At Kern River, high injection rates from closely spaced wells resulted in mounding of water and subsequent fracturing. Disposed water flowed up the fractures to stratigraphically higher oil-producing zones, increasing water cut. In order to maintain disposal capacity, Chevron formed a team of geologists and engineers who drafted formal disposed water management plans. Waldron offered copies of these plans to DOE, BPOI, and Chevron engineering at Elk Hills.

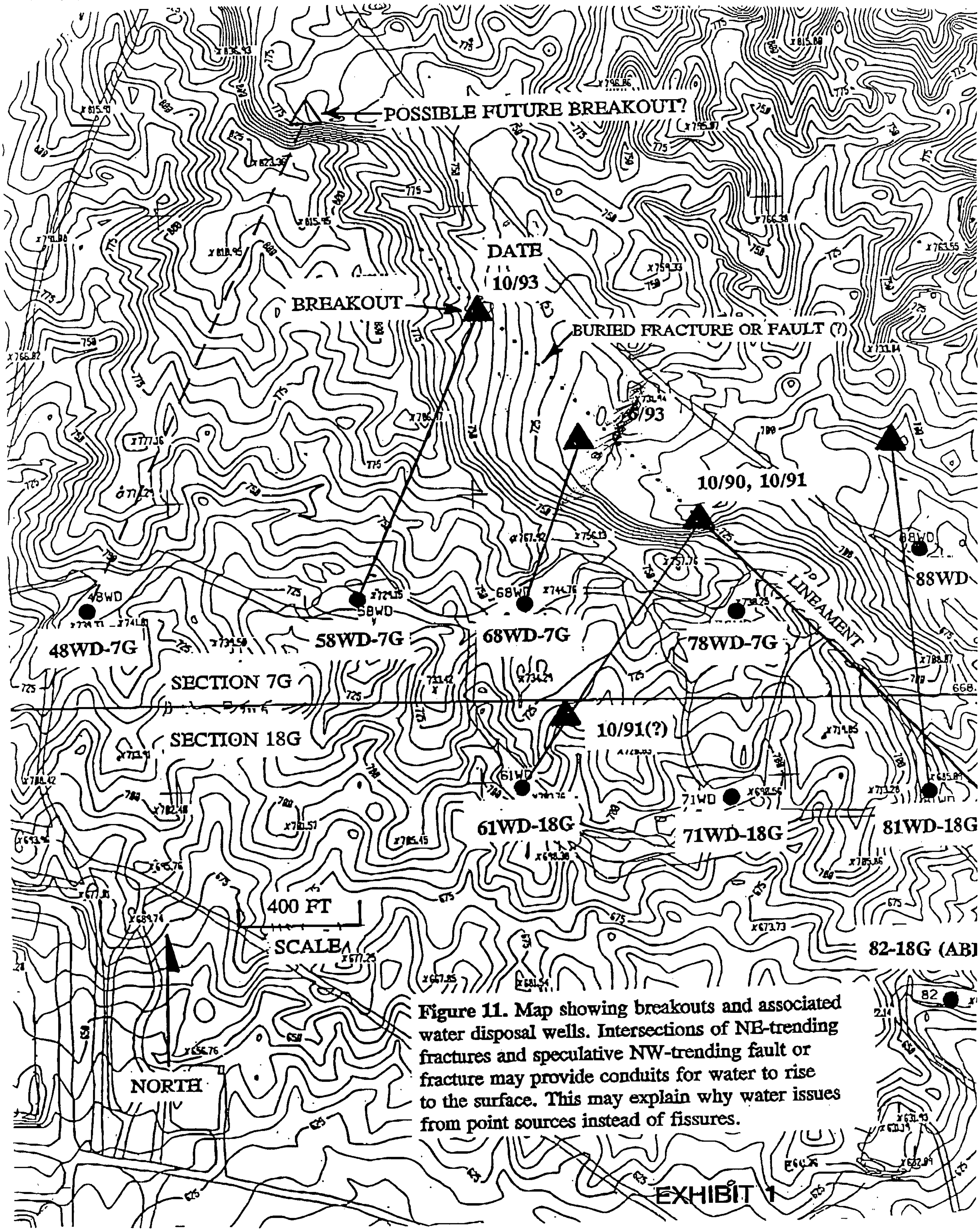
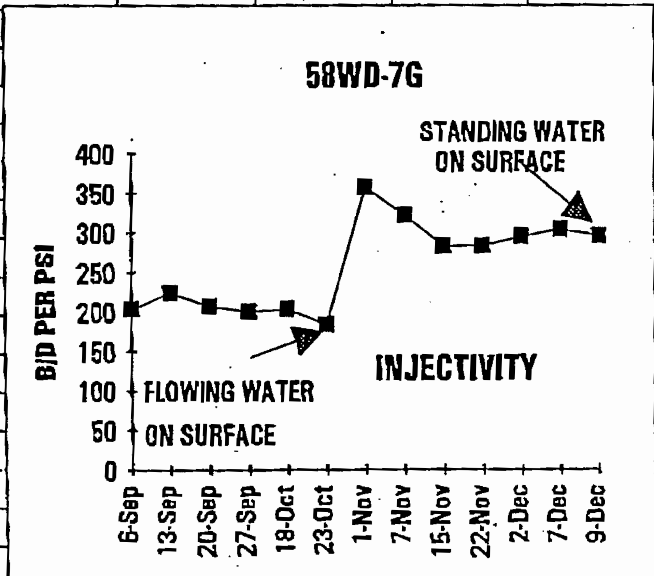


Figure 11. Map showing breakouts and associated water disposal wells. Intersections of NE-trending fractures and speculative NW-trending fault or fracture may provide conduits for water to rise to the surface. This may explain why water issues from point sources instead of fissures.

58WD-7G	TUBING FRAC. PRESS. - 251 PSI,			FRAC. RATE - 19,000 B/D				
DATE	TUBING	RATE	STATIC	DIFF.	%FRAC	%FRAC	B/D	COMMENTS
	PSI	B/D	PEN	PEN	PSI	B/D	PER PSI	
6-Sep	125	25485	5.00	6.40	50%	134%	204	
13-Sep	115	25883	4.80	6.50	46%	136%	225	
20-Sep	125	25883	5.00	6.50	50%	136%	207	
27-Sep	125	25087	5.00	6.30	50%	132%	201	
18-Oct	125	25485	5.00	6.40	50%	134%	204	
23-Oct	151	27874	5.60	7.00	60%	147%	184	FLOWING WATER
1-Nov	51	18317	3.20	4.60	20%	96%	358	
7-Nov	54	17521	3.30	4.40	22%	92%	322	
15-Nov	65	18317	3.60	4.60	26%	96%	283	
22-Nov	65	18317	3.60	4.60	26%	96%	283	
2-Dec	65	19114	3.60	4.80	26%	101%	295	
7-Dec	51	15530	3.20	3.90	20%	82%	303	
9-Dec	51	15132	3.20	3.80	20%	80%	296	STANDING WATER



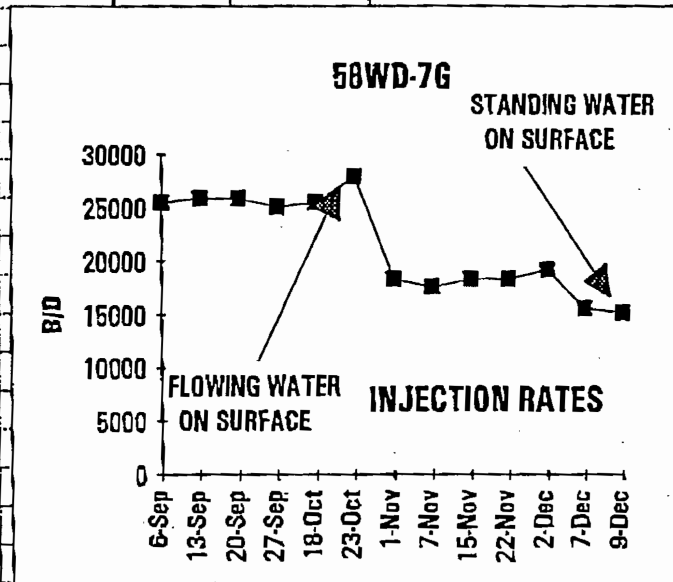


EXHIBIT 4